

APPENDIX I – Dobson and Brewer Spectrophotometers

The measurement of total column ozone with spectrometers is an analytical technique with a long historical background. The first measurements with a Dobson Ozone Spectrophotometer were conducted in the mid-twenties. A global network of Dobson instruments was established during the years following the first International Geophysical Year in 1957. A modern instrument, the Brewer Ozone Spectrophotometer, was developed in the nineteen seventies and introduced into the global network in 1982 with the delivery of instruments to Greece, Sweden, Germany and Canada

The basic measurement principle of both types of spectrometers is the same. The thickness of the ozone layer is determined by comparing the intensity of solar radiation that has passed through the atmosphere at wavelengths in the ultraviolet that are strongly and weakly absorbed by ozone. The Dobson utilizes a kind of internal virtual 'ozone layer' (a variable attenuator called an 'optical wedge') to measure the intensity ratio of two wavelengths, the Brewer directly measures the intensity of light at a number of different wavelengths in the ultraviolet. The physical principles and instrumental characteristics of these methods are well known and acknowledged and therefore do not need any further justification as a primary technique for the NDACC. It is, however, important, to characterize the individual instruments of both spectrometer types and to determine their specific calibration constants.

The following sections are intended to describe the methods used to certify the accuracy and precision of the instrument calibrations and the homogeneity and quality of their data records. As much special literature and manuals already exist, references to relevant publications and links to corresponding web pages will often replace detailed description of the methods used.

Quality Criteria for the Evaluation of New Instruments and Instrument Teams

Independent Evaluation of the Instrument Design, Observation Schedule, and Data Analysis

General: As both the Dobson and Brewer spectrophotometers have been approved by the WMO as reliable high-quality instruments for more than 25 years, NDACC has evaluated them as accepted tools to monitor the ozone layer. The only criteria that must be met for Dobson and/or Brewer stations to be accepted into the NDACC is demonstration that observations and regular tests have been performed according to the corresponding Standard Operating Procedures (SOP's) for the respective instruments. In addition, documentation is required showing that the instruments are in good calibration as a result of regular calibration exercises. The quality of the data records are certified by comparison with other instruments either directly or via satellite transfer. In the following sections the specific methods, documents and SOP's will be itemized in detail.

Dobson: The old manuals of G.M.B. Dobson (Dobson Ozone Spectrophotometer – III Observers' Handbook, Pergamon Press, 1957) and W. Komhyr (Operations Handbook – Ozone Observation with a Dobson Spectrophotometer, WMO Global Ozone Research and Monitoring Project Report No. 6, 1980) are still valid documents for the successful operation of Dobson instruments. The recently published revision of Komhyr's handbook

(Robert Evans' WMO GAW Report No. 183, 2008) and other relevant information and publications are available at <http://www.esrl.noaa.gov/gmd/ozwv/dobson> and <http://www.chmi.cz/meteo/ozon/dobsonweb/welcome.htm> and give an update of the SOP's taking into account the instrumental modifications (e.g. new electronics, other sort of quartz for the prisms etc.) and the development of new test and observation methods. A special manual (Archie Asbridge, Dobson Spectrophotometer Calibration Notes. GAW/MOHP, 2000) was published mainly as an instruction sheet for Dobson experts at the World and Regional Dobson Calibration Centers. Moreover, it contains useful information for Dobson network operators to gain a better understanding of the performance of Dobson spectrophotometers.

Most of the older stations with long term records have written their own software for data analyses following the instructions in the manuals cited above. Software tools developed at the Solar and Ozone Observatory Hradec Kralove (Czech Republic), which are offered on their homepage (address see above) as freeware are a valuable aid for new stations. The Japan Meteorological Agency (JMA) has also made available analysis software. A written request is required for this free software, which is in use at Asian stations, and is now being evaluated for use at some US stations.

It should be clear, that all Dobson stations have the necessary manuals/SOP's available and that all observations and tests are carried out in accordance with these documents. If other software is in use, it should be compared with the recommended software from Hradec Kralove or JMA to confirm the accuracy of the analyzed ozone values.

The documents referenced, the name of the software used, observation schedules, and any other pertinent information should be published by the Principal Investigators in a NDACC metadata file to document the performance of the station.

Brewer:

Brewer operations are largely automatic with the instrument running unattended according to predetermined schedules. This means that much of the detail with which the Dobson operator's manuals are concerned is actually taken care of by the Brewer operating software. Both technical and operating information is provided by the Brewer manufacturer in the form of published manuals including the operator's manual and the service manual. (See <http://www.kippzonen.com/?news/78232/New+Brewer+Spectrophotometer+for+Koran+Meteorological+Administration.aspx> on the Kipp & Zonen web site)

A publication called Brewer Standard Operating Procedures draft document is now available for download from http://www.woudc.org/data/document/index_e.html or <http://www.io3.ca/index.php?id=1034> .

WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting reports are issued approximately every two years and document the activities of the Brewer User's workshops. These publications are available on line from the WMO at <http://www.wmo.int/pages/prog/arep/gaw/gaw-reports.html> and provide extensive and detailed information about the operation and the use of the Brewer ozone Spectrophotometer.

General background information on making ozone measurements can be found in the CIMO Guide 7th edition available at

Instrument and Data Analysis Intercomparison

General: A considerable number of intra- and inter-instrumental comparisons have been carried out and published in the past. Two very important investigations comparing Dobson and Brewer data with satellite data have been performed by Labow and Fioletov. The results of these comparisons were presented and discussed at WMO SAG Ozone meetings and are used to determine the quality (in particular, homogeneity) of long-term records and to detect possible problems. Support to solve these data uncertainties is offered.

Quality Criteria for the Evaluation of Continuing Instruments and Instrument Teams

General: Four different methods can be applied to check and guarantee continuously high data quality, which is the basic requirement for NDACC stations.

- Regular performance of the daily and monthly tests according the SOP's and application of the results.
- Regular comparison of Dobson and Brewer data at the station, if both instrument types are operated simultaneously or with data from instruments at near-by stations.
- Comparison of the ground-based spectrophotometer data with the satellite overpass data provided by NASA (<http://toms.gsfc.nasa.gov/ozone/ozoneother.html> for older data before 2005 and <http://avdc.gsfc.nasa.gov/index.php?site=1593048672&id=28> for the latest OMI-data). In addition detailed intercomparisons between satellite data and the most important ground stations have been performed by Gordon Labow from NASA and Vitali Fioletov from WO3UDC. Their results are very helpful in the assessment of the homogeneity of long term records and are publicly available.
- Regular participation in international intercomparison and calibration services.

Dobson: The main goals of the global Dobson calibration system consisting of one World Dobson Calibration Center (WDCC, NOAA, Boulder, USA) and of 5 Regional Dobson Calibration Centres (RDCC) as a WMO GAW infrastructure are:

- To transfer the calibration scale defined by the World Primary Dobson Spectrophotometer D083 (WPDS) into the Dobson part of the GAW ozone monitoring network through regional intercomparisons of spectrophotometers
- To assist in regular maintenance of Dobson instruments in the regions by technical services, spare parts or expert missions
- To implement new technologies and GAW rules, e.g., QA procedures, software and IT tools for processing of observations and data transfer

Within this framework, regular Dobson Intercomparisons and Services are offered (every four or five years for each instrument according the WMO recommendations). A majority of the Dobsons employed in the global network take part in these campaigns. These activities enable the assessment and evaluation of the active Dobsons and guarantee the quality of the obtained data records.

Well maintained Dobsons should agree within $\pm 1\%$ (initial calibration). If not, data re-processing is recommended and supported on request. The reports can be provided through the RDCC's and it is recommended to include them in the metadata sets for each instruments. All affiliated NDACC Dobson stations should be invited to grant the permit of

publication of the reports on their instruments' calibration services (see also next section). This permission can be considered as crucial contribution to fulfill the NDACC quality criteria in the long term.

Brewer: The calibration of Brewer instruments is traceable to a Triad of Brewers at the Environment Canada facility in Toronto, Canada. The reference instruments in Toronto are recalibrated every few years at Mauna Loa Observatory in Hawaii. Some instruments are physically taken to Toronto for calibration but the most are calibrated at the observing stations by comparison with traveling Standard Brewer #017. There is also a secondary reference site at Izana in Spain. The reference maintained by the three double monochromator Brewers (Brewer MkIII) in Spain is monitored with respect to the calibration reference in Toronto through frequent visits to Spain by Canadian instruments that have been calibrated against the Toronto triad. Reports of the outcome of these calibration intercomparisons are posted for general access on the International ozone Services (IOS) website and the World Ozone and Ultraviolet radiation Data Centre (WOUDC) website.

Changes in Instruments and Data Analysis

General: All instrumental changes, which are generally performed during calibration campaigns, should be reported in metadata files deposited in the corresponding data centers (NDACC DHF as well as the co-operating WOUDC in Toronto).

General changes in the data analysis, like the application of new ozone cross-sections are normally decided upon and initiated by the official WMO GAW bodies. The working group representatives act as intermediaries between those bodies and the individual station PI's or the managers of the RDCC's / RBCC's, to ensure that the new coefficients will be introduced into the data processing algorithms.

Planned instrument changes, such as replacing a Dobson with a Brewer, should be carefully prepared and carried out following the detailed instructions and recommendations described in the WMO GAW Report No. 149, Comparison of Total Ozone Measurements of Dobson and Brewer Spectrophotometers and Recommended Transfer Functions (by Staehelin, Kerr, Evans and Vanicek).

Dobson: The easiest way for the Dobson Principal Investigators to record the calibration history of their instruments is to give permission to the responsible RDCC's to submit detailed calibration reports to the data centers. All necessary information about the performance of the Dobsons at the station and during the calibration campaign is documented in these reports. New data processing algorithms and especially new calibration coefficients normally result in reprocessed data (partial or complete records), which is submitted to the data bases and identified with an updated version number. A description of the various versions in the metadata files is helpful and highly recommended.

Brewer: Most Brewers are re-calibrated by International Ozone Services. When a calibration takes place, the instrument PI is given a report on the outcome of the comparison. These reports should be submitted to the data centre to be archived and made available to those who use the data from the database. The results from comparisons carried out by other means should be similarly documented in the data centre. The IOS reports serve as a useful guide of the content of the report.